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A Review of H_2 Detection in Light Water Reactor Containments

Edward C. Neidel, John G. Castle, Jr., James E. Gover

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A REVIEW OF H_2 DETECTION IN LIGHT WATER REACTOR CONTAINMENTS

E. C. Neidel, J. G. Castle, Jr., and J. E. Gover

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A B S T R A C T

Hydrogen detection systems are being installed in existing LWRs and are planned for new plants. This study outlines the potential uses of hydrogen concentration measurements in nuclear power plant containment buildings including the control of hydrogen mitigation systems. The types of hydrogen sensors that are available commercially are reviewed and our principal concerns about the limitations of these sensors for nuclear power plant applications are identified. We suggest sensor design modifications that have potential for improving the performance of existing hydrogen sensor systems.

We describe the sensing methods and sensor technology that utilities are employing for hydrogen measurement. An alternative in-containment measurement system is also discussed.

TABLE OF CONTENTS

		Page
I.	Introduction	9
	A. Background	9
	1. Uses of Hydrogen Concentration Measurements	9
	2. Location of Hydrogen Concentration Sensors in Containment	10
	3. Effect of Containment Volume	11
	B. Relationship of the Measurement of Hydrogen Gas to Mitigation and Control	11
	1. Sensitivity of Hydrogen Measurement vs. The Bounds For Safe Ignition	12
	2. Measurement Time Constant vs. Time Allowed For Decision to Ignite	13
	3. Surviving The Environment Within Containment	13
	C. Physical Properties of Hydrogen Gas and Sensor Specificity	14
II.	Results of Survey as of January 1981	15
	A. Objectives of the Sandia Effort on Hydrogen Detection	15
	B. Responses From Instrument Suppliers	16
	C. Performance Data on Gas Detection Systems Purchased for LWR Service	17
	D. Air Sampling Systems Being Installed in Containment	21
	E. Proposal of New Sensor Performance Criteria for Hydrogen Detection Systems	25
III.	Summary of Conclusions and Recommendations	27
	A. The Need For Hydrogen Concentration Measurements	27
	B. Status of Hydrogen Sensor Technology	27
	1. Thermal Conduction Sensor	28
	2. Electrochemical Cells	28

TABLE OF CONTENTS - Cont.

	Page
C. Accuracy and Minimum Detectable Concentration Measurement of Hydrogen	29
D. In-Containment Hydrogen Sensors	29
References	30
Appendix A	31
Appendix B	41
Distribution	57

I. INTRODUCTION

A. Background

Generation of hydrogen gas inside containment has been observed to occur in light water reactors (LWRs) during loss-of-coolant accidents (LOCAs).[1,2] The major source of hydrogen is an oxidation reaction of water with the zirconium in the fuel cladding. This reaction requires that the fuel cladding reach temperatures in excess of 2000°F. Hydrogen was generated in the accident at Three Mile Island (TMI-2) in large quantities.[3,4] Its combustion in the TMI-2 containment building apparently produced a pressure pulse whose peak value was recorded at 28 psi, a value which is well below the design limit of the containment structure.[5,6]

Several methods of reducing risks from combustion of high concentrations of hydrogen gas have been proposed and are under study.[5] One method of mitigation being planned by several utilities is referred to as deliberate ignition. In this mitigation scheme a set of diesel engine glow plugs or a set of spark coils are distributed throughout containment to ignite the hydrogen-air mixture at a low hydrogen concentration. If the concentration of hydrogen is sufficiently low, its combustion is expected to produce no serious damage to the containment structure.[7]

1. Uses of Hydrogen Concentration Measurements

There are a variety of technical and institutional uses for hydrogen concentration measurements in nuclear power plants. These are described in the following.

Research currently underway may show that continuously-operating igniters might reliably ignite hydrogen-air mixtures at concentrations low enough to be safe for many accident scenarios. However, under certain conditions currently considered possible, dangerously high concentrations could conceivably develop. In either case, safety would be clearly enhanced by knowledge of the actual hydrogen concentrations as a function of time at important locations in containment. The reliability and efficacy of deliberate ignition schemes could therefore be enhanced by the prompt and accurate detection of hydrogen.

Measurement of hydrogen concentration throughout the various compartments of containment also provides the plant operator with information that is useful to plant control for purposes other than the need to activate or turn-off mitigation schemes. For example, if a mitigation system is employed, hydrogen concentration measurements provide the operator with a direct measurement of the success of his mitigation efforts throughout the containment compartments.

An inventory of the amount of hydrogen released from the primary system into containment would be a useful measure of the degree of oxidation of the fuel rod cladding during a LOCA. Hydrogen concentration measurements could provide the operator with a definitive measure of the extent of core damage in real time. In addition, when the hydrogen concentration history is combined with oxygen measurements, the generation and combustion of hydrogen during an accident can be better characterized. Such information would be vital in later reconstructions of the accident sequence and follow-on safety analyses.

The TMI-2 accident made hydrogen generation during a nuclear plant accident a newsworthy event and also demonstrated the need for the nuclear power industry to concern itself not only with the physical health of the public but also with their fears of nuclear power plant accidents. In future accidents, should they occur, the public will expect to be informed about the status of hydrogen generation in the plant. Assurance through direct measurement of hydrogen concentration that there is no danger of hydrogen combustion compromising the containment structure is an important goal in maintaining public confidence in the safety of nuclear power systems.

2. Location of Hydrogen Concentration Sensors in Containment

It is beyond the scope of this study to determine precisely where hydrogen sensors should be located in various containment buildings. Such a determination will be plant specific. However, qualitative reasoning leads one to anticipate certain trends in sensor location strategy.

Since the source of hydrogen in the containment building is the reactor core, hydrogen release into containment will first occur somewhere at the boundary of the primary coolant system. Early detection of its release requires hydrogen concentration sensors to be located with care, possibly at regular intervals around the complete primary system. The precise definition of the critical locations depends upon definition of an acceptable delay time between release and detection, and on the rate at which hydrogen mixes with containment air.

Depending upon the detailed design of openings into various compartments and rooms of the containment building, it could be possible for hydrogen to collect in certain of these. If sensor technology were adequately developed to yield high performance at low cost, it could easily prove to be cost effective to locate a sensor within each room rather than to determine exactly which rooms should have sensors located in them.

It is apparent that one can anticipate extensive application of hydrogen sensors throughout the containment building. It is clear that an important key to providing the operator with a complete map of hydrogen concentration is the availability of a low cost hydrogen sensor system that: (1) can be located throughout the containment building, and (2) requires a minimum of electrical penetrations and cables.

3. Effect of Containment Volume

Nuclear power plants with containment volumes greater than about 2 million cubic feet and design pressures above 45 psig may have sufficient size and strength to tolerate hydrogen combustion for most accident scenarios. If analyses determine this to be the case, then deliberate ignition systems that do not depend upon hydrogen concentration measurements might be adequate. Hydrogen-air combustion in smaller containments could develop excessive pressures and therefore mitigation steps should be taken. Control in the smallest containments with free volumes of approximately 300,000 cubic feet, is currently accomplished by inert atmospheres. Since oxygen is not present in these systems, there is no danger of hydrogen combustion unless oxygen is released during the accident. The types of LWR plants that are viewed as most in need of hydrogen mitigation capabilities are those with intermediate sized containment structures with volumes in the range of 1 to 1.5 million cubic feet.[4] Hydrogen mitigation measures that go beyond current deliberate ignition designs may be needed in these plants. There are 3 operating plants and some 25 plants with intermediate volume containments under construction.

B. Relationship of the Measurement of Hydrogen Gas to Mitigation Control

The adequacy of existing hydrogen detection systems depends on the role hydrogen measurement would play in the decision to mitigate any hazard. Detailed consideration of the various hydrogen release scenarios following LOCAs is outside the scope of this report, but a few general comments are in order. The rate of hydrogen generation depends on the temperature of the cladding and the availability of steam.

These, in turn, depend on the accident conditions including break size (or valve opening) and the degree to which the emergency core cooling systems (ECCS) function (zero or partial). For some accidents, the evolved hydrogen may be temporarily confined to the primary system and later released in a controlled fashion. For other accidents (e.g., pipe breaks), the release of hydrogen into containment will be uncontrolled and will depend on generation rates and transport mechanisms in the primary system. If a bubble containing hydrogen develops in the primary coolant system and a controlled release into containment is possible, then the rate of release should be kept slow enough to avoid creating a plume of potentially explosive gas in containment.

Current deliberate ignition schemes require activation prior to the generation of hydrogen. For sufficiently small or slow releases, this system may be adequate. However, hydrogen concentration measurements would still provide an important record that the ignition system has, in fact, served its purpose. Faster releases, however, may produce local pockets of dangerously high hydrogen concentrations. The role of hydrogen concentration measurements would then be to determine the hydrogen concentration at representative locations[8] to provide the plant operator with sufficient information to form a basis for the decision to ignite. Of course, the operator must receive this information in a timely fashion to make a decision.

1. Sensitivity of Hydrogen Measurement vs. The Bounds For Safe Ignition

Raising the minimum detectable concentration of any given type of hydrogen gas sensor can usually allow the sensor system to be more durable, less expensive, and have a faster response time to changes in hydrogen gas concentration. Therefore, considerable care should be exercised in setting the value of the minimum hydrogen concentration as high as possible while remaining appropriate for the specified upper bound for safe ignition.

The appropriate upper bound for safe ignition in any given igniter location depends on accident scenario, plant geometry and mixing rates. Whenever the hydrogen concentration is on the increase, the instrument must respond to concentrations well below the upper bound and rapidly enough to permit a mitigation decision before the critical concentration is reached. A reasonable value for the minimum

detectable concentration may be 1% hydrogen with a corresponding accuracy specification* of ±.5% hydrogen for LWR service. Some might prefer the higher confidence attained through ±.25% hydrogen accuracy.

2. Measurement Time Constant vs. Time Allowed For Decision to Ignite

Some LOCA scenarios call for a decision by the plant operator or by a control computer. With the operator in the loop and with a decision delay time of a minute or so,[4,5] it seems reasonable to allow no more than the first half of that time delay to be consumed by obtaining measurements. Therefore, we recommend that the time constant for the hydrogen detection system to respond to a step change in the hydrogen concentration in the air near an igniter be no more than one-half (one-fourth would be more conservative) of the time delay allowed for a decision to actuate that igniter. If one assumes a decision time delay of one minute, the time constant should be about 30 seconds or less for the system response.

3. Surviving the Environment Within Containment

Water can cause difficulties with hydrogen gas sensing in two ways: in the air sample being sensed, and in any of the electronics supplying power to and extracting the signal from the sensor units. Protecting the electronics from water is a matter of careful packaging. As long as the water in the air sample remains in vapor form, the common hydrogen sensors will be affected very little. Condensed water, however, tends to burn out the hot wires in thermal conductivity detectors and some catalytic detectors. To overcome this burnout, one manufacturer includes a drying chamber on the input air sampling tube to bring the dewpoint below 300°F. Presumably this operating limit could be raised somewhat to meet environmental requirements on water content.

If hydrogen sensors are to be located inside containment, ionizing radiation will affect the hydrogen measurement in two ways: (1) Electrical currents proportional to the instantaneous dose rate and the mass of the sensing elements are generated in the sensors and electronics. (2) Performance degradation is usually proportional to the accumulated dose delivered to the sensor and electronics

*to the confidence level of 68+% corresponding to one standard deviation.

sections of the instrument. It is common practice to shield sensors from external beta radiation. The degradation is expected to be increased above that for the usual gamma dose in the hydrogen sensor units because the sensor units bring in air which may contain post-LOCA radioactive gases and particles that are emitting gamma rays and beta particles. This radiation may add an appreciable and damaging dose to the critical portions of the sensor units as well as deposit an electric charge on the surface of insulators located internal to the sensor.

C. Physical Properties of Hydrogen Gas and Sensor Specificity

The binding of the two electrons of the hydrogen molecule is responsible for its unusually large heat of oxidation and a set of absorption lines in the ultraviolet and infrared regions of the electromagnetic spectrum. However, optical sensing that depends on the light absorption characteristics of hydrogen are affected by fog, resulting in indeterminate readings. Catalytic combustion sensors have been made which rely on the large heat of combustion of hydrogen gas, but they also sense hydrocarbon gases which burn with oxygen. Therefore, they will not be specific indicators of hydrogen gas in containment.

The low mass of the hydrogen molecule gives hydrogen gas several of its distinct properties. Two properties which are readily detected are the high thermal conductivity[9] (about seven times that of air and ten times that of steam) and the variation of sound speed in hydrogen gas with frequency in the 1 to 10 MHz range. Thermal conduction sensors are not affected by other gases provided the hydrogen is burned to water vapor after passing the sample cell and before passing the reference cell. Even for single cell conduction measurements, the only other gas with comparable heat conduction is helium. Acoustic detectors have been demonstrated[11] for NASA; they are likely to be affected by fog in the ultrasonic beam.

The low density and low viscosity of hydrogen gas combine to give a special inertial property that can be detected in a sensor operating as a fluidic oscillator.[12] Again, such devices have been made and demonstrated for NASA.

The special diffusion characteristics of hydrogen through many solids permit rather specific filtering of the sample gas. The fact that only hydrogen permeates a properly chosen filter membrane or layer leads to a variety of sensors which are rather specific to hydrogen. For example, the permeation of heavy metal films, such as palladium, by atomic hydrogen produces specific changes in the film's electrical

properties. Sensors have been made which rely on resistance changes due to hydrogen adsorption within the film resistor. For another example, certain plastics, in the polyimide class, are permeable to hydrogen much more than to water and other gas components of containment air. This allows materials, such as KAPTON,* to serve as specific diffusion-limited filters for H_2 gas. When such a filter covers an electrochemical cell[2] whose electrolyte dissolves hydrogen, the combination gives an output current specific to the rate at which H_2 molecules are diffusing through the filtering film. Correlation of the output with the partial pressure of H_2 requires only that the temperature of the film be known (because the diffusion rate is thermally activated) and that the air sample flow be constant across the film surface. An absolute measurement of hydrogen concentration also requires that the ambient pressure be known.

II. RESULTS OF SURVEY AS OF JANUARY 1981

A. Objectives of the Sandia Effort on Hydrogen Detection

The purposes of our work were to: (1) review the commercially available instrumentation for measurement of hydrogen gas concentration in containment air, (2) estimate the adequacy of this equipment for application in nuclear power plants, and (3) report the plans of the electric power utilities for using hydrogen detection systems to improve the safety of LWR operation. Steps for increasing the efficacy of existing hydrogen detection systems are also suggested. Equipment calibration schedule may be a key issue to successful LWR service and is of great concern to the utilities but is dealt with only in a cursory way in this report for lack of confirming operational data.

Discussions of the types of hydrogen sensors which are commercially available were presented in two papers at a recent workshop.[9,10] These papers included the results of the authors' surveys and indicated the principal characteristics of these sensors.

The published specifications of gas detectors and their suppliers are listed in Appendix A. The operating principles and one representative set of performance data for each type of gas detector identified during this survey are included in Appendix B.

*KAPTON is a DuPont trademark.

Our approach has been to query the instrument suppliers for performance data on available equipment for the detection of hydrogen and/or oxygen and to query the nuclear power utilities on their use of these instrument systems. Our survey of the instrument industry is reasonably complete on hydrogen detection.

B. Responses From Instrument Suppliers

Information on commercially available hydrogen and oxygen gas detectors was received from more than 30 instrument suppliers. The specifications received from most of the suppliers indicated the available gas detectors were essentially standard models of industrial or laboratory-style instruments. Two noteworthy exceptions were the Thermal Conduction Detectors, Models K III and K IV, from the Delphi Division of Com-Sip, Inc., South El Monte, CA, and the diffusion-limited Electrochemical Detector (ECD) for hydrogen from Exo-Sensors, Inc., Laguna Hills, CA. Exo-Sensors indicated that their sensor units are undergoing tests to qualify as safety grade units for service inside LWR containments. A Com-Sip unit is the only unit to have completed the above tests. As summarized in Table 1, units from both companies have been sold to nuclear power utilities. This compilation includes all the responses received as of January 20, 1981. Approximately sixty of the thermal conduction (TCD) systems have already been delivered, according to the supplier. The three diffusion-limited cell (ECD) systems are in the final stages of preparation for delivery; they include a total of ten ECD sensor units.

Table 1. Survey of Utility Purchases of Hydrogen Gas Detection Systems for LWR Use.

SENSOR TYPE:	TCD	ECD
Purchases by Electric Utilities, Number of Detection Systems	120	3 (10)
Location of H_2 Sensor Units:	Outside Containment	Inside Containment
Manufacturer:	Com-Sip	Exo-Sensor
Model Performance Data:	(Table 2)	(Table 3)

Nuclear power utilities have installed gas chromatographs (GC) for long-term monitoring of contamination within containment. With appropriate sensors, these GC units can include hydrogen in their output spectrum but the usual cycle time is of the order of 10 minutes. Therefore, gas chromatographs are not useful for continuous, fast response hydrogen detection.

C. Performance Data on Gas Detection Systems Purchased for LWR Service

The published data on the performance of the gas detection systems that have been purchased by electric power utilities are summarized in Tables 2 and 3. The purchased systems fall into two categories, as indicated in Table 1, according to sensor type and location. The majority of the systems purchased to date rely on heated-wire, thermal-conduction (TCD) sensors which will be located outside of containment. Containment air is sampled for each sensor by circulation of the containment atmosphere through two pipes which penetrate the containment wall.

A few of the recently purchased hydrogen detection systems rely on the diffusion-limited electrochemical cell (ECD) sensors located inside containment. These ECD systems will bring out several pairs of wires per detector through the containment wall, to the system's microprocessor located outside containment. In light of the indicated high cost of containment penetrations and cables, it may be cost effective to transfer high temperature, radiation-hardened signal processing electronics technology (developed for defense applications) to the sensor manufacturer.[12] These electronics would operate in the severe environments postulated for LOCAs and would reduce the number of containment penetrations and cables required for the many hydrogen sensors that might be needed.

The performance data on TCD systems from Com-Sip, Inc., indicate, in Table 2, the characteristics of instrument systems as currently supplied, but may not be their limiting performance. The temperature of 300°F is, for example, the normal operating temperature of the oven containing the three gas chambers in series: the sample cell, the catalytic oxidation cell, and the reference cell. In order to handle 100% humidity input air above 300°F, the operating temperature of the oven would need to be raised or the input air dried more than in the present units. The pump which circulates containment air through the sample piping at nearly 20 cubic feet per hour is located outside containment in present utility systems. It appears to us that both the TCD sensor and this pump with minor modifications are likely to survive and perform within

Table 2. Performance Data Of Thermal Conductivity Detector

(Data Supplied by Manufacturer)

Manufacturer:	Com-Sip, Inc. South El Monte, California
Models:	K III H_2 K IV H_2 & O_2
Temperature:	40 - 300^{o}F
Pressure Range:	0 - 60 psig
Humidity Range:	0 - 100% Including Entrained H_2O
Flow Rate:	18 ft^3/hr Pump Capacity
Sample Rate:	150 cm^3/min (0.32 ft^3/hr)
Range:	0 - 10% H_2, 0 - 100% O_2
Reading Response Time:	90% of reading in less than 60 secs.
Accuracy:	$\pm$ 2% Full Scale
Repeatability:	$\pm$ 1% Range
Zero & Span Drift:	$\pm$ 2% in 7 days
Radiation:	1 X 10^6 rads (1 X 10^8 with seal modifications)
Qualification Tests:	IEEE 323-(1974), IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations IEEE 344-(1975), IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment For Nuclear Power Generating Stations
Detector Location:	Outside Containment
Analyzer Location:	Outside Containment

Table 3. Performance Data of Diffusion-Electrochemical Detector.
(Data Supplied by Manufacturer)

Manufacturer:	Exo Sensors, Inc. Laguna Hills, CA.
Model:	H_2
Acceptance Test:	Duration, 48 hours
Temperature:	75 - 185°F
Pressure:	15 psia
Rel. Humidity:	30 - 100%
Qualification Test:	Duration, 92 days
Temperature:	203 - 338°F
Pressure:	15 - 75 psia
Rel. Humidity:	30 - 100%
Radiation:	3.2×10^7 rads
Accuracy:	±2% Full Scale
Range:	0 - 10% H_2 (0 - 20% @ Max. Temp. & 60 psia)
Reading Response Time:	60% of reading in 120 seconds
Detector Location:	Inside Containment
Analyzer Location:	Outside Containment

the post LOCA environment inside containment. The air sample to be analyzed is a small fraction bled off the main flow of 18 cubic feet per hour. The sample rate of 0.32 cubic feet per hour is the rate appropriate for the existing laboratory/ process type TCD sensors. The sample rate could be faster for larger size TCD sensors, allowing both speed and signal strength to be increased. The reading response time as listed, appears to be equivalent to a time constant of 30 seconds. The accuracy stated in Table 2 is ±2% Full Scale, which means ±0.2% H_2. Such an uncertainty means that the minimum detectable concentration is at least 0.4% H_2 in the air sample.

It is interesting to note that when this accuracy requirement is relaxed by a factor of 2.5 to a value of ±0.5%, the same sensor is claimed to be operable with a time constant near 10 seconds. This is a change we recommend for LWR service.

We believe that there are several improvements that could be made to thermal conduction type sensors. The electrical output of this cell could be increased by increasing the volume of the cell. This would increase its sensitivity to hydrogen and improve the cell's immunity to electrical noise. We are concerned about the ability of this cell to operate continuously for many years. Should water enter the hot wire regions of the cell, the sensor wires are likely to burn out. We believe that the environmental ruggedness of the cell could be improved by increasing the diameter of the sensor wires, employment of conformal coatings on the wire to prevent water from contacting the sensor element or utilization of other wire materials that are insensitive to water, and operating the wire at lower temperatures.

The performance data on ECD systems from Exo-Sensors, Inc., indicate, in Table 3, a sample of the test observations. It is not clear what limiting performance is available from these units. The diffusion rate can readily be increased but the extent of reduction from the present time constant of some 120 seconds is not yet clear. The operation of an ECD system produces an output current proportional to the number of hydrogen molecules reaching the electrolyte per second and conversion to H_2 gas pressure above the diffusion filter requires measuring and correcting for the temperature of the diffusion layer. With the microprocessor outside containment, this temperature correction requires at least one added pair of wires through the containment wall. The accuracy stated as ±2% Full Scale means ±0.4% H_2 and is equivalent to a minimum detectable hydrogen concentration of 0.8% H_2. The test data we have received indicate also that the microprocessor in these

ECD systems has been programmed to correct for spurious current output due to high dose rate from gamma radiation, an effect which appears to be reversible in these ECD sensors.

We believe that there are acceptable design alternatives that would result in the response time of the ECD sensor being decreased. These include reducing the thickness of the hydrogen diffusion membrane and heating the entering gas to increase the diffusion rate of hydrogen through the membrane. This sensor's electrical output could be increased by increasing the area of the diffusion membrane. The manufacturer is pursuing several means of reducing the drift that is occasionally observed.

This type of sensor design has several attractive design features. These include its inherent immunity to water and its self-powered characteristic.

D. Air Sampling Systems Being Installed in Containments

Details are not yet available on the arrangements of Exo-Sensor detectors being installed within containments by the Northern States Power Company of Minneapolis, Minnesota. The survey did obtain the layouts planned or being installed for several of the Com-Sip systems.

Fig. 1 shows schematically that the two separate H_2 detection systems being installed at Oconee, North Carolina, by Duke Power Company have their thermal-conduction sensor analyzer units outside of containment. Each detection system will be able to sample containment air through any one of its three ports or sample air at the recombiner through either of the two inlet sampling ports. Since the inlet ports of the second detection system are adjacent to the ports of the first systems, some measure of confirmation of any one reading of H_2 concentration will be available from the second system through the adjacent port. A similar installation of two parallel systems at McGuire, North Carolina, by Duke Power Company, is shown in Fig. 2. The piping by which the air samples are returned to containment is not shown in either of the figures.

At Sequoyah, Tennessee, the Tennessee Valley Authority is installing two Com-Sip H_2 detection systems with the units outside of the steel containment wall but the method of sampling containment air is quite different from the Duke layouts. As shown in Fig. 3, inlet ports are being installed at four different locations within Sequoyah containment and thereby will sample separated volumes of air continuously. This continuous sampling at each inlet in Sequoyah has the advantage of shorter time delay for an air

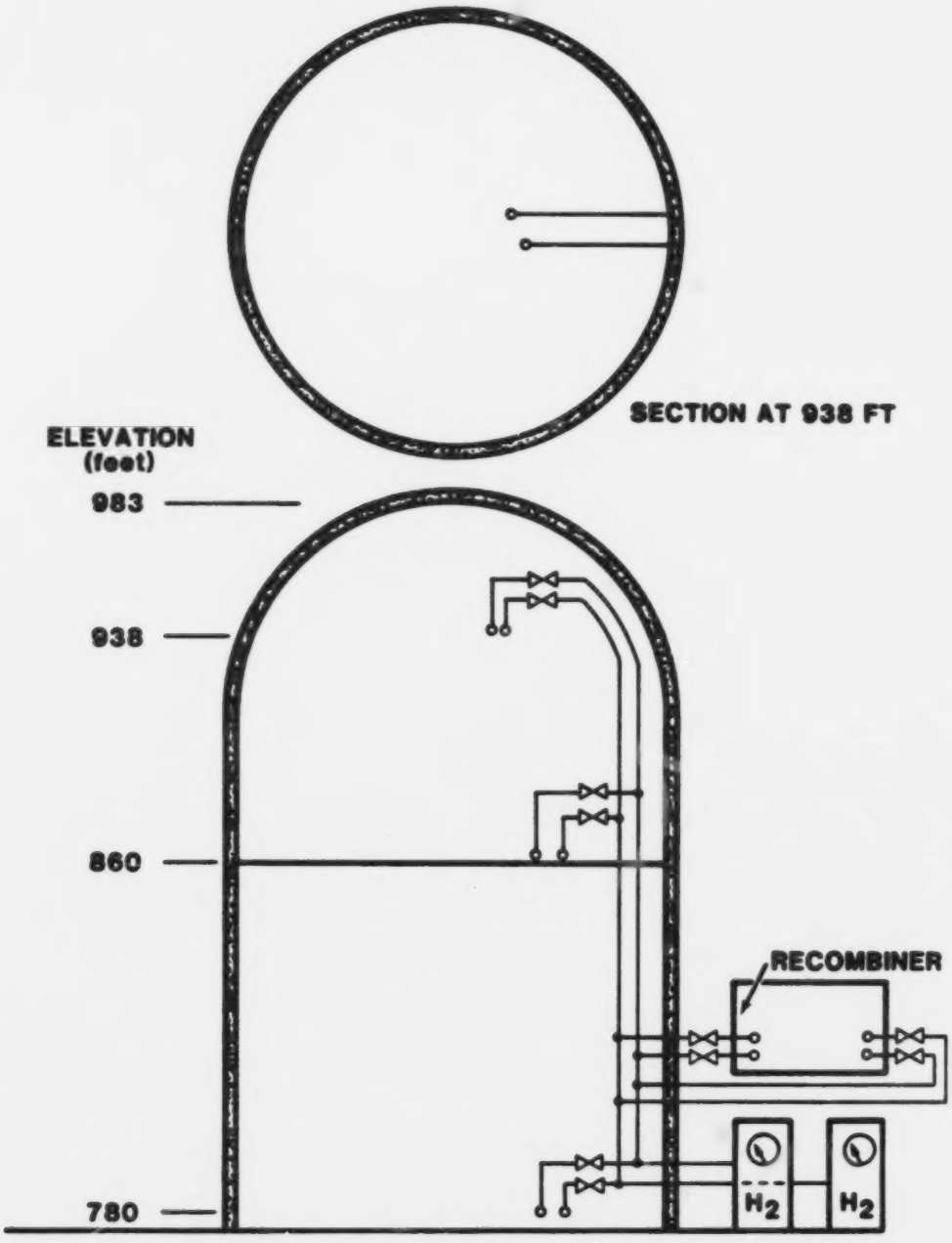

Fig. 1. HYDROGEN DETECTION SYSTEMS AT DUKE - OCONEE. The two separate systems have their sensor-detector-display units outside containment. Each can sample the containment air through anyone of its five ports in time sequence or all five in parallel. The return lines are not shown.

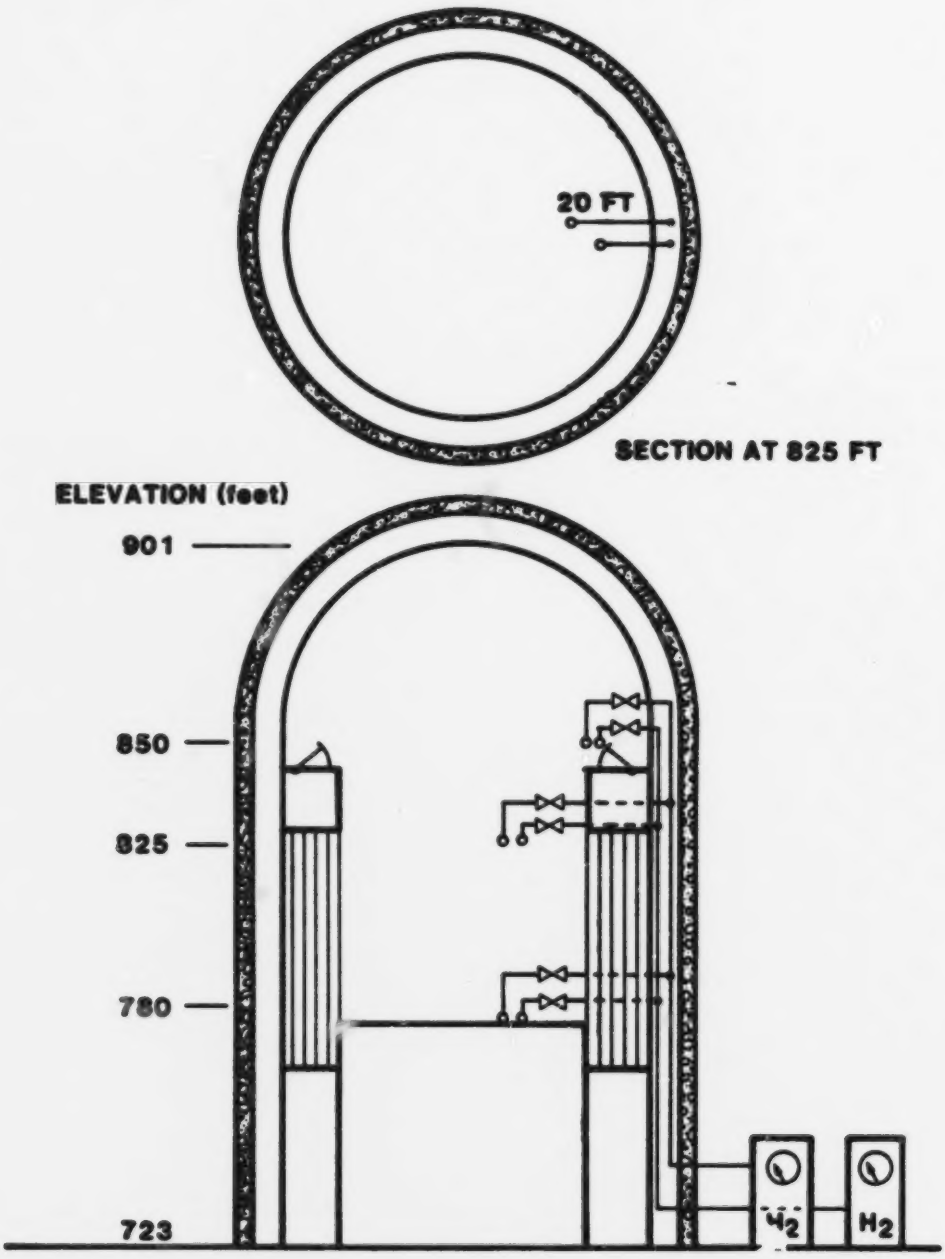

Fig. 2. HYDROGEN DETECTION SYSTEMS AT DUKE - McGUIRE. The two separate systems will have their sensor-detector-display units outside containment. Each will sample containment air through any one of its three ports in time sequence or through all three in parallel. The return lines are not shown.

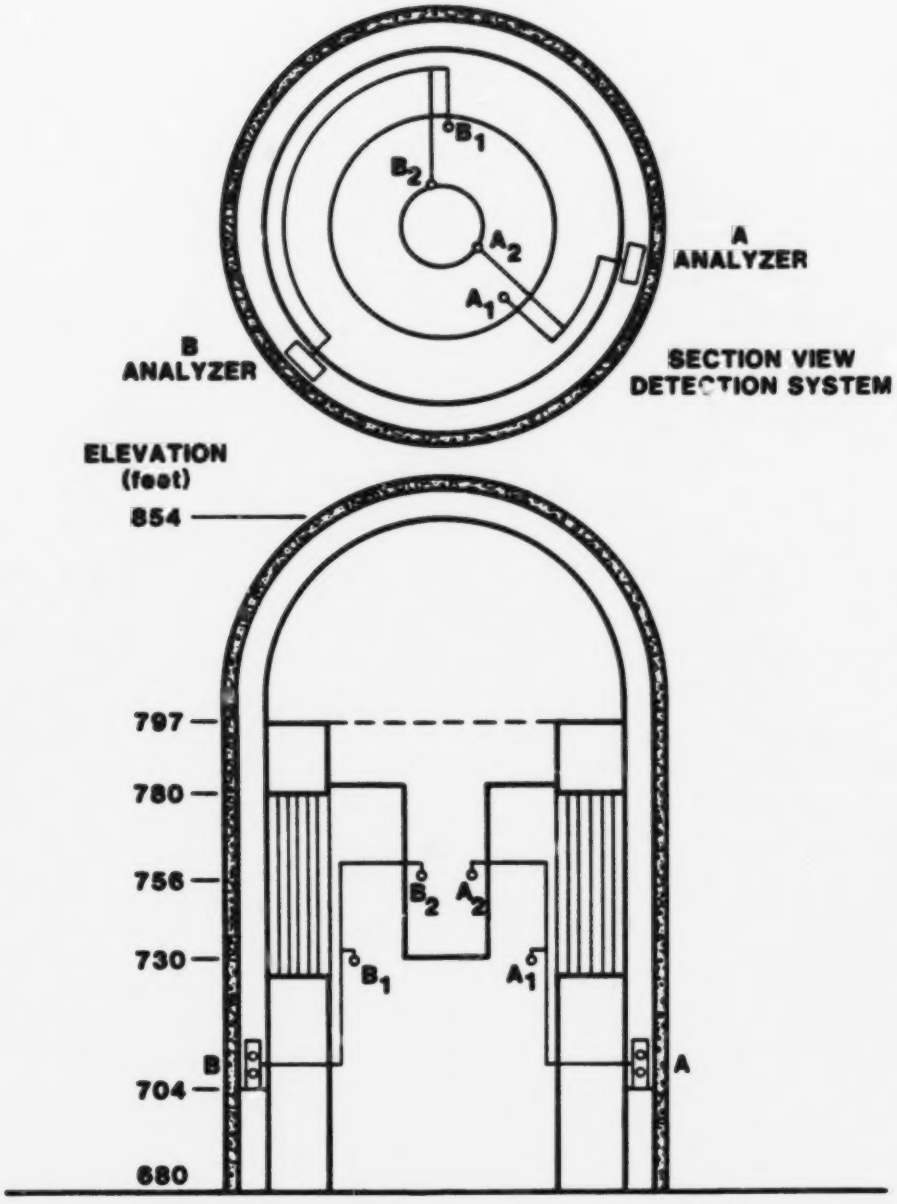

Fig. 3. HYDROGEN DETECTION SYSTEMS AT TVA - SEQUOYAH. The two separate systems will have their sensor-detector-display units outside the steel containment. Each will sample containment air through its two ports in parallel. The length of sampling pipe from inlet port B_2 to the sensor unit of system B is over 200 feet. Return lines are not shown.

sample from a given inlet to reach the sensor. The corresponding disadvantage of reduced sensitivity to local variations in concentration applies when containment air is not thoroughly stirred. Increased sampling is clearly desirable within the Sequoyah containment. Again the return lines are not shown in our schematic layout.

The time delays in the sampling pipes have been calculated using 18 cubic feet per hour flow and represent a significant increase in the detection system response time. For example, the 3/8" pipe carrying air from B_2 inlet to the B system sensor in the annulus outside the Sequoyah steel wall is 204 feet long. Diffusion is slow compared to the normal system pumping speed of 7 cm/sec with the B_1 port plugged. The lapsed time from the instant of a step increase in the H_2 concentration at the B_2 inlet to the arrival of gas at the analyzer chamber with a H_2 concentration of up to 60% of the inlet step size is calculated to be 38 seconds. This delay essentially doubles the system response time over that of the sensor alone. In addition to having cost advantages, an in-containment sensor system would provide other benefits relative to a plumbed sampling system. Plumbing pipes throughout containment has limitations in terms of the number of containment compartments that it is practical to sample. (We advocate a measurement of hydrogen in each separate containment compartment and multiple measurements in the more critical compartments). Sampling containment air through pipes and locating sensors outside of containment requires the pipes to penetrate the containment boundary. Safety considerations suggest this to be an undesirable yet acceptable design feature. Alternative measurement methods that avoid pipe penetrations through the containment structure are preferred.

E. Proposal of New Sensor Performance Criteria For Hydrogen Dectection Systems

The staff at TVA, Knoxville, TN, has apparently decided to seek hydrogen detection systems which respond to increased H_2 concentration with a time constant of 15 seconds. As discussed in the Introduction, this number is consistent with confirming the H_2 reading within a decision delay time of the order of one minute.

A summary of the proposed device performance criteria requested by TVA of potential suppliers in October 1980 is listed in Table 4. In order for the system response to be as short as 15 seconds, the sampling pipes must be very short, e.g., 30 feet of 3/8" pipe gives 5 seconds delay at the present pumping rates of 18 cubic feet per hour. Therefore, sensor operation inside containment is being considered. The existing sensors may perform inside but the electronics will not survive the expected gamma dose.

Table 4. Proposed Performance Characteristics For Hydrogen Detector-Analyzer

(Submitted to 14 prospective suppliers in October, 1980)

Requester:	Tennessee Valley Authority Knoxville, Tennessee
Model:	H_2
Temperature:	350°F Max
Pressure:	50 psig Max
Radiation Dose:	10^8 rads
Accuracy:	$\pm$0.5% H_2
Range:	0 - 25% H_2
Reading Response Time:	Not to exceed 15 seconds
Detector Location:	Inside Containment
Survival Environments:	Post LOCA and H_2 Burn (Steam & Condensation)
Quantity Required:	30 to 40 per unit, Non-Class 1E Equipment

The new value of accuracy, namely, $\pm$0.5% H_2 concentration, is well below the danger zone and therefore is probably of sufficient precision. It is expected that a larger minimum detectable H_2 concentration will permit available sensors to be operated with shorter time constants. For consistency with the accuracy value of $\pm$0.5% H_2 and a reasonable confidence figure, the lower range limit (minimum detectable concentration) should be raised to a value equal to approximately twice the standard deviation of 0.5% H_2 called for in the accuracy requirement.

III. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

A. The Need For Hydrogen Concentration Measurements

Direct measurements of hydrogen concentration in each separate compartment of reactor containment buildings would provide the plant operator with a thorough map of hydrogen concentration. These measurements could be used for (1) mitigation system control in intermediate sized containments, (2) assessment of the success of hydrogen mitigation schemes in any containment structure that employs a hydrogen mitigation system, (3) providing information on the state of cladding material oxidation, and (4) maintaining public confidence that in any accident, hydrogen is under control.

B. Status of Hydrogen Sensor Technology

Utilities are purchasing two types of hydrogen sensors for LWR service. These are thermal conduction sensors from Com-Sip, Inc., and diffusion limited electrochemical cells from Exo-Sensors, Inc. We did not identify any commercially available hydrogen sensor whose performance would be superior to that of these two types. However, there are two other types of sensors that may also have potential. These are optical sensors and acoustic sensors. Both could sample a larger region of containment than thermal conduction or electrochemical sensors. Neither the optical sensor nor acoustic sensor has been developed to the commercial status of electrochemical or thermal conduction sensors.

It was beyond the scope of this work to conduct experiments to gain first hand experience with the use of the thermal conduction or electrochemical cells. Hence, our evaluation of the adequacy of these sensors for LWR service is limited to manufacturers' information, conversation with utility users, and our understanding of sensor design features. Nevertheless, we have formulated some opinions that are summarized in the following:

1. Thermal Conduction Sensor

The thermal conduction cell is fast enough in its response time to be adequate for LWR service. The electrical output of this cell could be increased by increasing the volume of the cell. This will improve the cell's immunity to noise for both in-containment and outside-containment applications. The ability of this cell to operate continuously for years is suspect, particularly if water should enter the hot wire regions of the cell, because of the high operating temperature used for the sensor wires. We believe the ruggedness of this sensor could be improved by increasing the diameter of the sensor wires, employment of conformal coatings on the sensor wire, employment of alternative wire materials, and operating the sensor wire at lower temperatures. The development of signal conditioning electronics for a thermal conduction cell would permit this type of cell to be operated in containment as a two wire system. The development of multiplexer technology would permit multiple thermal conduction cells to operate in containment with minimum impact on containment penetrations and cable runs.

2. Electrochemical Cells

Under accident conditions involving fast releases, the electrochemical cell being purchased by the utilities may have too slow a response time to be useful for controlling deliberate ignition systems. Under other release conditions, its response time may be adequate. We believe that the response time of this sensor can be shortened by thinning its hydrogen diffusion membrane or by heating the entering gas to increase the diffusion rate of hydrogen through the membrane. This type of sensor is relatively insensitive to water in the entering gas sample.

The electrical output of this type of sensor could be increased by increasing the area of the diffusion membrane. Increased electrical output would reduce the sensor's noise sensitivity. Its reported drift characteristics may be improved by the modifications being evaluated by the manufacturer.

Each electrochemical cell requires multiple penetrations (approximately 9) for in-containment application. Transfer of radiation-hardened microprocessor technology to the instrument vendor and the development of multiplexer technology would permit multiple electrochemical cells to operate in containment with minimum impact on containment penetrations and cable runs.

Conversations with both manufacturers of hydrogen sensing instruments reveal that both are willing to modify the design of their sensors to improve performance.

C. Accuracy and Minimum Detectable Concentration Measurement of Hydrogen

There are potential advantages to raising the minimum detectable hydrogen concentration to 1% hydrogen. These include faster instrument response, less frequent calibration, simplified instrument design, and improved instrument reliability. We are not able to identify any need for hydrogen concentration data when the concentration is less than 1% or when the change in concentration is less than a 1% change. We also suggest that the corresponding accuracy requirement be set as high as $\pm$0.5 percent hydrogen concentration.

D. In-Containment Hydrogen Sensors

The current method employed by most of the utilities for measuring hydrogen concentration in containment is to sample containment air through long pipes which extend outside of the containment wall to where the hydrogen sensors are located. Although this design alternative is the only one available to the utilities at the present time, we consider it undesirable from several points of view. (1) The response time of the measurement system is increased by the time required for the gas to flow through the sampling pipes. This delay time is as much as 30 seconds for some of the plants we reviewed. It could be much longer in other plants. (2) This method has practical limits in terms of the number of containment compartments that can be sampled. We recommend sampling of each separate compartment and multiple samples in larger compartments. (3) Implementation of this method requires that pipes be run through the containment wall, thus the containment boundary is extended. For safety reasons we view this to be an acceptable but undesirable design feature. (4) This method of sensing hydrogen is not cost effective in comparison to locating the sensors inside of containment and multiplexing their outputs on a common cable and containment penetration.

Although the in-containment hydrogen sensing system described is not currently available commercially, we judge that a two year development program would yield a system that could measure hydrogen concentration during and following a severe accident.

References:

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12. IEEE Conference on High Temperature Electronics, held March 25-27, 1981, at Tucson, Arizona, with joint sponsorship of NASA, DOE, and Los Alamos National Laboratory.

APPENDIX A

Appendix A is a list of gas detector and gas analyzer suppliers with an abbreviated description of the published operation specifications of their equipment. The gas detector suppliers are grouped under eight different detector type headings. Gas chromatograph systems utilize a variety of gas detectors and are featured separately.

The Thomas Register (Thomas Publishing Co., New York, NY) and the AAAS Guide to Scientific Instruments, 1980-81, were used as sources of gas detector suppliers. Another source was exhibitors contacted at the National Safety Congress during October 1980 in Chicago.

Brochures and literature were received from over 30 suppliers. The data shown in the appendix have been taken from these sources. Space limitations precluded listing all of the data available. The data shown were judged to be the most pertinent of this application.

An additional 24 suppliers were identified. Some could not be contacted. The others supplied either no data or supplied data of no interest to us.

CATALYTIC-TYPE DETECTORS

SUPPLIER	MODEL	TEMPERATURE °F	RANGE %	RESPONSE TIME (SEC)	SUPPLIER'S COMMENTS
Bacharach Pittsburgh, PA	H_2	-40 to +200		5, 2.5%* 30, 4.5%*	*Response Time for CH_4; Flow Rate, 2 Ft^3/Hr
Control Instrs. Fairfield, NJ	CGS	-40 to +212	H_2, 0-4	1	Filament Life, 1 Year 16 Channels Available
Dynamation Ann Arbor, MI	LCD Combo		H_2, 0-7 O_2, 0-25		O_2 Detector is Diffusion-Electrochemical Type
English Electric Valve Co., Ltd. Elmsford, NY	VQ 1			2	Response Time: 2 Seconds for 1.25% in 2.5% Conc.
ERDCO Evanston, IL			H_2, 0-4	5	Response Time: 5 Seconds When Gas Conc. is Twice the Set or Alarm Point Position. Sensor to Analyzer to 5000 Ft. Eight (8) Stations Available
Gas Tech Mtn. View, CA	1177		H_2, 0-4		
	ProTechTor		H_2, 0-4 O_2, 16-22		O_2 Detector is Diffusion-Electrochemical Type
General Monitors Costa Mesa, CA	480	-65 to +200	H_2, 0-4	4, 2%	16 Channels Available
Internat'l Gas Detectors, Ltd. W. Yorkshire, UK	Mark III	-40 to +180	H_2, 0-4		Low Filament Temperature, 176F, is Posion Resistant & Enhances Life

Instrument Data Taken From Supplier's Brochures, Published Literature, and Private Communication.

CATALYTIC-TYPE DETECTORS (Cont.)

SUPPLIER	MODEL	TEMPERATURE °F	RANGE %	RESPONSE TIME (SEC)	SUPPLIER'S COMMENTS
Mine Safety Appl. Pittsburgh, PA	510	-40 to +200	H_2 0-4 CH_4 0-5	H_2 5, 2% CH_4, 5, 2.5%	Sensor Cannot Detect Combustible Gas in Steam or Inert Atmosphere
Rexnord Sunnyvale, CA	810 910				3-Wire System 2-Wire System
Scott Aviation Lancaster, NY	Quadflex	-40 to +400	H_2 0-4	3, 2%	16-Channel Multiplex System
Teledyne San Gabriel, CA	102 122	32 to +125 40 to +160	H_2, 0-4 H_2, 0-4	20 3.6% 15 3.6%	
COLOR-CHANGE TYPE DETECTOR					
National Draeger Pittsburgh, PA	0_2 H_2		0_2, 5-23 H_2, 0.5-3.		Black Color Changes to Pale Grey with 0_2 Yellowish Green Color Changes to Pink with H_2. Possible Ignition Source If Used Beyond 3% H_2. Both Units Are One-Shot, Hand-Held Devices.
DIFFUSION - ELECTROCHEMICAL-DETECTOR TYPE					
Bacharach Pittsburgh, PA	0_2			25	Standard Housing, Not Explosion Proof, 100 Ft. Range with .25 in Pipe

Instrument Data Taken From Supplier's Brochures, Published Literature, and Private Communication.

DIFFUSION - ELECTROCHEMICAL-DETECTOR TYPE (Cont.)

SUPPLIER	MODEL	TEMPERATURE °F	RANGE %	RESPONSE TIME (SEC)	SUPPLIER'S COMMENTS
Bio-Marine Malvern, PA	O_2 O_2		O_2, 0-25 O_2, 0-100		Poisoned by Over 10% CO_2, 10 Hr
Exo Sensors Laguna Hills, CA	H_2	50 +300	H_2, 0-10 H_2, 0-10	120, 60% 600-720, 90%	Pressure 15 - 17 psig Radiation Dose 32 Mrads 3 Systems sold to Power Utilities
General Electric San Jose, CA	H_2	Ambient 200	H_2, 0-10 H_2, 0-10	7200, 90% 1800, 90%	
Gas Tech Mtn. View, CA	1313 O_2 OX-80 O_2		O_2, 0-25 O_2, 0-50		
	1214 H_2 O_2		H_2, 0-4 O_2, 0-25		H_2 Detector Is Catalytic Type
	ProTechTor		H_2, 0-4 O_2, 16-22		H_2 Detector Is Catalytic Type
Internat'l Gas Detectors, Ltd. W. Yorkshire, UK	O_2	32		5, 24%	
Sipin New York, NY	O_2	32 to +100	O_2, 18-22	10, 17%	
Teledyne San Gabriel, CA	O_2	32 to +125		7, 90% 13, 90% 30, 90%	7 Sec with B-1 Cell 13 Sec with B-3 Cell 30 Sec with C-3 Cell

Instrument Data Taken From Supplier's Brochures, Published Literature, and Private Communication.

MICRO FUEL CELL DETECTOR TYPE

SUPPLIER	MODEL	TEMPERATURE °F	RANGE %	RESPONSE TIME (SEC)	SUPPLIER'S COMMENTS
Dynamation Ann Arbor, MI	O_2	+30 to +125	O_2, 0-25	10, 90%	
Enmet Ann Arbor, MI	O_2				Multichannel Monitoring Alarmed at 17.5 to 19.5% O_2 Cell Life 10 - 12 Months
Teledyne San Gabriel, CA	O_2			5-60, 90%	
		RESISTANCE TEMPERATURE DETECTOR TYPE			
Control Instrs. Fairfield, NM	FFA	-40 to +150	H_2, 0-4	10	Indefinite Sensor Life Consumes 8 CC/Min C_3H_8
		SOLID-STATE DETECTOR TYPE			
Dynamation Ann Arbor, MI	H_2		H_2 0.0005 to 0.005*	300	*Data for H_2S Sensor Life to 5 Years
Enmet Ann Arbor, MI	H_2	570	H_2 0.4-2.4		Sensor Life to 3 Years in Clean Air
Internat'l Sensor Technology Santa Ana, CA	H_2	120	H_2 0-.01 0-.10 0-4.0	PPM Range 30, 90% 0-4% Range 10, 90%	Eight (8) Channels Available

Instrument Data Taken From Supplier's Brochures, Published Literature, and Private Communication.

SOLID-STATE DETECTOR TYPE (Cont.)

SUPPLIER	MODEL	TEMPERATURE °F	RANGE %	RESPONSE TIME (SEC)	SUPPLIER'S COMMENTS
Interscience Palo Alto, CA	CH - 2D CH - 2F2		CH_4 0-.001 CH_4 0-50 H_2 0-.001 H_2 0-.01 H_2 0-.1 H_2 0-1.0		Sensor Produced by Taguchi of Japan.
Smith & Denison Hayward, CA					No Literature Received. Detector Described As Using Taguchi Sensor from Japan.
THERMAL-CONDUCTIVITY DETECTOR TYPE					
Beckman Fullerton, CA	7C	40 to 100	H_2 0-.05 H_2 0-100	30, 95%	Pressure: 10 - 50 psig Flow Rate: 0.1 - 0.7 ft^3/hr.
Com-Sip S. El Monte, CA	K III, H_2	40 to 120	0-10 H_2 0-20	60, 90%	Pressure: -2 to 60 psig Flow Rate: 18 - 20 ft^3/hr. Tested to IEEE 323 & 344 More Than 120 Units Purchased by Nuclear Power Utilities
	K IV H_2 & O_2	40 to 120	H_2 0-10 O_2 0-20	60, 90%	
Ion Track Instrs. Burlington, MA	H_2		H_2, 0.03 min.		
Teledyne San Gabriel, CA	225 CM	40 to 431	H_2, 0-10	120, 90%	

Instrument Data Taken From Supplier's Brochures, Published Literature, and Private Communication.

THIN-FILM RESISTOR DETECTOR TYPE

SUPPLIER	MODEL	TEMPERATURE °F	RANGE %	RESPONSE TIME (SEC)	SUPPLIER'S COMMENTS
Resource Systems Hanover, NJ				420, .01%	Integrating Device with Memory. One-Shot Device, Registers Only Concentration Increases.

Instrument Data Taken From Supplier's Brochures, Published Literature, and Private Communication.

GAS CHROMATOGRAPH

SUPPLIER	AVAILABLE SENSOR TYPES							SUPPLIER'S COMMENTS
	TCD	FID	ECD	FPD	PID	TSD	HECD	
Analytical Instrument Development Avondale, PA	X	X	X	X	X			
Beckman Fullerton, CA	X	X						#6710, Range 0.01 to 100% #6750, 1 to 6 Analyzers, 3000 Ft. Away, Temp 32-100°F, Press 40 - 60 psig, 100 ml/min.
Bendix Lewisburg, WV	X	X		X				Installed as Auxiliary Equipment at two reactor sites. Cycle Time, 6 to 10 min.
Foxboro Houston, TX	X	X						TCD for less Sensitive Use. FID for Ambient Air & Water Use. 15-Point Sampling.
Varian Palo Alto, CA	X	X	X	X		X	X	Some Opportunity to Interchange Detectors

* THERMAL CONDUCTIVITY DETECTOR

*FLAME IONIZATION DETECTOR

* ELECTRON CAPTURE DETECTOR

* FLAME PHOTOMETRIC DETECTOR

* PHOTOIONIZATION DETECTOR

* THERMIONIC SPECIFIC DETECTOR

* HALL ELECTRONIC CONDUCTIVITY

Instrument Data Taken From Supplier's Brochures and Published Literature.

OTHER MANUFACTURERS

SUPPLIER	COMMENTS
Acme Engineering Products Mooer, NY	CO Detectors Only
Alarm Supply Livonia, MI	Residential Units
American Gas & Chemical Northvale, NJ	Non-Quantitative Output
Andros, Inc. Berkeley, CA	Infrared & Exhaust Detectors
CL, Inc. Detroit Lakes, MN	No Phone
Combustion Engineering Windsor, CT	No Response
Danford Portland, ME	Clorine & Hydro-Carbon Detectors
Delta Atlas Thibodaux, LA	Discontinued
Dynadyne Phoenix, MD	No Response
Ecolyzer Elmsford, NY	Detectors for Other Gases
Gateway Scientific Santa Ana, CA	Smoke Detectors
Hayes Republic Div. Michigan City, IN	Discontinued

OTHER MANUFACTURERS

SUPPLIER	COMMENTS
Interscan Chatsworth, CA	Detectors for Other Gases
New Jersey Meter Co. Patterson, NJ	Soap & Water System
Opto Electronics Petaluma, CA	Infrared Detectors Only
Pyrotronics Cedar Knolls, NJ	Smoke Detectors
Rev Co. Santa Ana, CA	Motor Home Gas Detectors
Sensor, Inc. Ann Arbor, MI	No Response
Sentry Equipment Oconomowoc, WI	Sample Conditioning Systems
Shigoto Far East Co., Ltd. New York, NY	No Response
Thermo Electron Hopkinton, MA	No Response
UE Systems New York, NY	Leak Detectors
U. S. Safety Service Kansas City, MO	No Response
Westclox Div. Peru, IL	No Response

APPENDIX B

Appendix B contains operating principles of the various types of H_2 gas detectors identified during the survey. Also included is one set of performance data for each detector type. The data were taken from brochures and literature supplied by the manufacturers.

Reference #10 is another source of H_2 detector information.

CATALYTIC BURNING DETECTOR

The catalytic burning detector measures the differential effect on two similarly coated filament leads, one of which has an active catalyst coating. The sample gas passes unchanged through the reference cell to the active cell where the H_2 undergoes catalytic combustion increasing the temperature and thereby increasing the resistance of the active coated lead.

The resistance increase is a measure of the H_2 concentration in the gas sample and is measured by the unbalance created in a bridge circuit containing the two filaments.

The catalyst can be poisoned by silicones, halogens, and lead compounds. The high filament operating temperature needed to activate the catalyst reduces the filament operating life. Any liquid water in the gas sample which reaches the heated filaments causes filament failure. Oxygen is required for operation.

PERFORMANCE DATA

CATALYTIC BURNING DETECTOR

MANUFACTURER:	BACHARACH INSTRUMENT CO. PITTSBURGH, PENNSYLVANIA
MODEL:	H_2 SENSOR SPECIFICATIONS
TEMPERATURE:	-40 - 200 F
TEMPERATURE STABILITY:	$\pm$ 2% IN 100 F TEMPERATURE RANGE
AMBIENT EFFECTS:	
PRESSURE:	2mV CHANGE UP TO 2 ATMOSPHERES POSITIVE PRESSURES @ 60 F
HUMIDITY:	$\pm$ 1% CHANGE FOR SATURATED WATER VAPOR @ 77 F
AIR VELOCITY:	2mV CHANGE UP TO 120 FT/SEC.
FLOW RATE:	2 FT^3/HR
READING RESPONSE TIME:	(SPECIFIED FOR 5% CH_4 IN AIR)
	2.5% READING IN LESS THAN 5 SECONDS
	4.5% READING IN LESS THAN 30 SECONDS
REPEATABILITY:	1% FULL SCALE
ZERO DRIFT:	2% FULL SCALE IN 30 DAYS
CATALYST "POISONING":	THE DETECTOR ELEMENT IS RESISTANT TO ALL CATALYST POISONS INCLUDING GASOLINE VAPORS AND TRACE SILICONES. ABNORMALLY HIGH CONCENTRATIONS OF FREON, SILICONE VAPORS OR TETRA-ETHYL LEAD WILL CAUSE LOSS OF SENSITIVITY.
RANGE:	0 - 4% H_2, STANDARD 0 - 10% H_2, CUSTOMIZED FOR NUCLEAR POWER APPLICATIONS

DATA SUPPLIED BY MANUFACTURER

COLOR CHANGE DETECTOR

The color change detector available is a hand-held one-shot unit which utilizes a sealed glass tube containing chemicals unique for the subject gas. A measured amount of sample gas is introduced into the tube with a calibrated hand pump. The chemicals change color indicating the presence of the questioned gas. A graduated scale on the tube surface gives a quantitative reading of concentration in the gas sample. Tubes are available for over 140 gases. For 0_2 the color change reaction is from black to pale grey and for H_2 the color change is yellowish green to pink.

PERFORMANCE DATA

COLOR CHANGE DETECTOR

MANUFACTURER:	NATIONAL DRAEGER, INC. PITTSBURGH, PENNSYLVANIA
MODEL:	67 28081 O_2 CH30901 H_2
RANGE:	5 - 23% O_2 0.5 - 3% H_2
LIMITATIONS:	WHEN USED IN ENVIRONMENTS WITH H_2 CONCENTRATION GREATER THAN 3%, THE H_2 DETECTOR MAY BECOME AN IGNITION SOURCE.

DATA SUPPLIED BY MANUFACTURER

DIFFUSION - ELECTRO CHEMICAL DETECTOR

H_2 detectors of the diffusion-electro-chemical type rely on diffusion of H_2 gas through a suspended membrane followed by rapid absorption on the surface of the hydrogen-sensitive electro-chemical cell. Since the output electric current counts the H_2 molecules getting through the membrane, the output is proportional to the product of the partial pressure of H_2 above the membrane and the activation factor describing the temperature dependence of the diffusion coefficient. The available sensor systems have appropriate thermal sensing and compensation built in to their micro-processor controls. Typical response times are reported to be a couple of minutes. The available diffusion-electro-chemical type detectors appear to have adequate stability against heavy gamma doses but show considerable output current due to high dose rates; the latter can apparently be automatically compensated.

PERFORMANCE DATA

DIFFUSION-ELECTRO CHEMICAL DETECTOR

MANUFACTURER:	EXO SENSORS, INC. LAGUNA HILLS, CALIFORNIA
MODEL:	H_2
ACCEPTANCE TEST:	
TEMPERATURE:	75-185°F
PRESSURE:	1 ATMOSPHERE
REL. HUMIDITY:	30-100%
DURATION:	48 HOURS
QUALIFICATION TEST:	
TEMPERATURE:	203-338°F
PRESSURE:	1 - 5 ATMOSPHERES
REL. HUMIDITY:	30-100%
DURATION:	92 DAYS
RADIATION:	3.2×10^7 RADS
ACCURACY:	$\pm$ 2.% FULL SCALE
RANGE:	0 - 10% H_2 (0 - 20% @ MAX. TEMP. & 4 ATM.)
READING RESPONSE TIME:	60% OF READING IN 120 SECONDS
DETECTOR LOCATION:	INSIDE CONTAINMENT
ANALYZER LOCATION:	OUTSIDE CONTAINMENT

DATA SUPPLIED BY MANUFACTURER

SEMICONDUCTOR RESISTANCE DETECTORS

The semiconductor detector measures the change in resistance caused by the absorption of H_2 molecules on the surface of the semiconductor. The surface is usually an oxide of tin, iron or nickel. The absorption produces a decrease in electrical resistance proportional to the H_2 concentration present in the sample. The semiconductor detectors are comparatively inexpensive. This type detector can sense very low concentrations of H_2 but there are questions about degradation from exposure to high concentrations of H_2 and to high energy radiation.

PERFORMANCE DATA

SEMICONDUCTOR RESISTANCE DETECTOR

MANUFACTURER:	INTERNATIONAL CENSOR TECHNOLOGY SANTA ANA, CALIFORNIA
MODEL:	H_2
TEMPERATURE:	14 - 122°F
READING RESPONSE TIME:	(IN PPM RANGE) 30 SECONDS TO 90% FULL SCALE (IN 0 - 4% RANGE) 10 SECONDS TO 90% FULL SCALE
ACCURACY:	2%
ZERO DRIFT:	2% IN 3 MONTHS
MINIMUM DETECTION CONCENTRATION:	1 PPM
CALIBRATION STABILITY:	6 MONTHS
RANGE:	0 - 4% H_2

DATA SUPPLIED BY MANUFACTURER

THERMAL CONDUCTION DETECTOR

The thermal conductivity of hydrogen gas is over six times as large as that of O_2, N_2, H_2O, CO, or CO_2. The thermal conduction detector measures the differential effect on the heated filament in the sample chamber compared to the similar heated filament in the reference chamber as the sample of gas flows slowly through the sample chamber, through the middle chamber containing the catalyst which burns the hydrogen into H_2O, and then thorugh the reference chamber. The decrease in electrical resistance of the first heated filament, due to the presence of some H_2 in the sample cell, is measured by the unbalance of the bridge circuit containing the two filaments. The resistance change is quantitatively related to H_2 concentration by maintaining thermal stability of the chamber assembly and by comparison with known gas standards.

The response time can be shortened by increasing the minimum H_2 concentration to be observed. A severe limit is the dew point of the incoming gas sample; any liquid water in the cell causes filament failure. Oxygen must be present for the catalytic burning.

PERFORMANCE DATA

THERMAL CONDUCTIVITY DETECTOR

MANUFACTURER:	COM-SIP, INC. SOUTH EL MONTE, CALIFORNIA
MODEL:	K III H_2 K IV H_2 & O_2
ACCEPTANCE TESTS:	
TEMPERATURE:	40 - 300^{o}F
PRESSURE:	0 - 60 PSIG
REL. HUMIDITY:	0 - 100%
FLOW RATE:	18 FT^3/HR
SAMPLE RATE:	150 CM^3/MIN (0.32 FT^3/HR)
RANGE:	0 - 10% H_2, 0 - 100% O_2
READING RESPONSE TIME:	90% OF READING IN 60 SECS.
ACCURACY:	$\pm$ 2% FULL SCALE
REPEATABILITY:	$\pm$ 1% RANGE
ZERO & SPAN DRIFT:	$\pm$ 2% IN 7 DAYS
RADIATION:	1 X 10^6 RADS
QUALIFICATION TESTS:	IEEE 323-(1974), IEEE STANDARD FOR QUALIFYING CLASS 1E EQUIPMENT FOR NUCLEAR POWER GENERATING STATIONS IEEE 344-(1975), IEEE RECOMMENDED PRACTICES FOR SEISMIC QUALIFICATION OF CLASS 1E EQUIPMENT FOR NUCLEAR POWER GENERATING STATIONS
DETECTOR LOCATION:	OUTSIDE CONTAINMENT
ANALYZER LOCATION:	OUTSIDE CONTAINMENT

DATA SUPPLIED BY MANUFACTURER

RESISTANCE TEMPERATURE DETECTOR

The resistance temperature detector is a combustible gas detector. Unlike the catalytic burning type detector, it is not poisoned by lead, silicone or hydrogenated compounds.

It utilizes a small propane flame, located in an explosion proof cell, to burn flammable gases in the area. The increase in thermal energy generated by the combustion is detected by the resistance sensor. The sensor signal is proportional to the gas concentration in the cell.

PERFORMANCE DATA

RESISTANCE TEMPERATURE DETECTOR

MANUFACTURER:	CONTROL INSTRUMENTS, INC. FAIRFIELD, NJ
MODEL:	FFA
TEMPERATURE:	0 - 150°F
HUMIDITY:	0 - 100%
RANGE:	0 - 4%
ACCURACY:	± 3% FULL SCALE
ALARM ACCURACY:	± 1% FULL SCALE
REPEATABILITY:	± 1% FULL SCALE
RESPONSE TIME:	10 SECONDS
FUEL CONSUMPTION:	1 LB./MONTH PROPANE
IGNITION:	PUSH BUTTON IGNITION
REMOTE SENSOR LOCATION:	10,000 FEET MAXIMUM
LIMITATIONS:	MINIMUM O_2 CONCENTRATION 18% WITH STANDARD UNIT, 12% WITH OPTIONAL UNIT. AIR DILUTION REQUIRED FOR OPERATION ABOVE 4% H_2.

DATA SUPPLIED BY MANUFACTURER.

THIN FILM RESISTOR DETECTOR

The thin film resistor detector is a high resistance, thin layer of palladium oxide film deposited on a substrate. The resistance of the detector slowly decreases irreversibly when exposed to hydrogen. This type detector is sensitive down to 0.1% H_2 concentration where the time constant is many minutes. The resistor is an integrating device with a permanent memory and does not reverse the change in resistance when the concentration of hydrogen is decreased.

PERFORMANCE DATA

THIN FILM RESISTOR DETECTOR

MANUFACTURER: RESOURCE SYSTEMS, INC.
HANOVER, NJ

DATA NOT SUPPLIED BY MANUFACTURER

GAS CHROMATOGRAPHY METHOD

Gas chromatography is a method of gas analysis which separates gases and analyzes each component gas sequentially for some physical property. The physical property measured depends on which gas detector is being used in the chromatograph. Thermal conductive and flame ionization are two popular detector types. A total of seven types available from five suppliers are shown on page 38. Commonly, an electrical output from the detector drives a recording potentiometer to reproduce a pulse whose sequential location on the recording chart produces the qualitative identification while the pulse amplitude shows the quantitative measurement.

Although a gas mixture may be analyzed for a single component gas, e.g., hydrogen, in a reasonable length of time, perhaps in a minute, a second reading for confirmation may require considerably longer while the system is being purged for the second sample. The normal cycle time is about 10 minutes.

Gas chromatography is being used by the nuclear power industry as a back-up detector and to verify performance and calibration of containment-installed hydrogen detectors with faster response times.

Distribution:

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